The performance of TripleSpec at Palomar

Terry L. Herter, Charles P. Henderson, John C. Wilson, Keith Y. Matthews, Gustavo Rahmer, et al.

Terry L. Herter, Charles P. Henderson, John C. Wilson, Keith Y. Matthews, Gustavo Rahmer, Marco Bonati, Philip S. Muirhead, Joseph D. Adams, James P. Lloyd, Michael F. Skrutskie, Dae-Sik Moon, Stephen C. Parshley, Matthew J. Nelson, Frantz Martinache, George E. Gull, "The performance of TripleSpec at Palomar," Proc. SPIE 7014, Ground-based and Airborne Instrumentation for Astronomy II, 70140X (9 July 2008); doi: 10.1117/12.789660

Event: SPIE Astronomical Telescopes + Instrumentation, 2008, Marseille, France

The Performance of TripleSpec at Palomar

Terry L. Herter[a], Charles P. Henderson[a], John C. Wilson[b], Keith Y. Matthews[c], Gustavo Rahmer[c], Marco Bonati[c], Philip S. Muirhead[a], Joseph D. Adams[a], James P. Lloyd[a], Michael F. Skrutskie[b], Dae-Sik Moon[d], Stephen C. Parshley[a], Matthew J. Nelson[b], Frantz Martinache[a], George E. Gull[a]

[a]Cornell University, Space Sciences Bldg, Ithaca, NY, 14853, USA;
[b]University of Virginia, 530 McCormick Rd, Charlottesville, VA, 22903, USA;
[c]Caltech, Div of Physics, Math., & Astronomy, MS 320-47, Pasadena, CA, 91125, USA;
[d]University of Toronto, 50 St. George Street, Toronto, ON M5S 3H4, Canada;

ABSTRACT

We report the performance of Triplespec from commissioning observations on the 200-inch Hale Telescope at Palomar Observatory. Triplespec is one of a set of three near-infrared, cross-dispersed spectrographs covering wavelengths from 1 - 2.4 microns simultaneously at a resolution of ~2700. At Palomar, Triplespec uses a 1×30 arcsecond slit. Triplespec will be used for a variety of scientific observations, including moderate to high redshift galaxies, star formation, and low mass stars and brown dwarfs. When used in conjunction with an externally dispersed interferometer, Triplespec will also detect and characterize extrasolar planets.

Keywords: Near Infrared, Spectroscopy, Cross-Dispersed

1. INTRODUCTION

A joint collaboration between Cornell University, the University of Virginia, the California Institute of Technology, and the Jet Propulsion Laboratory resulted in the construction of three "identical" spectrographs (TripleSpec) for use on the Palomar 5-m telescope, the Apache Point Observatory 3.5-m telescope, and the Keck Observatories 10-m telescopes. The baseline design of TripleSpec is geared towards follow-up observations of sources found in surveys such as the Two Micron All-Sky Survey[1] (2MASS), the Sloan Digital Sky Survey[2] (SDSS) and the Spitzer Space Telescope[3]. In many cases the objects of interest such as brown dwarfs, dust obscured galaxies, and high-redshift galaxies are brightest in the near-infrared (NIR) or have visible rest frame diagnostic lines redshifted into this spectral region. Our goal was to design a single-object spectrograph with high enough spectral resolution to measure lines and spectral features in these objects and separate out the strong atmospheric OH airglow lines present in this part of the spectrum. In addition we coveted simultaneous coverage over a wide wavelength range and wished to achieve background limited performance on the low continuum levels between the OH lines in the J and H bands in reasonable integration times.

The resulting spectrograph, TripleSpec, covers the wavelength range from 1 to 2.45 μm simultaneously at a spectral resolution ($R = \lambda/\Delta\lambda$) of 2700 sampled at ~2.7 pixels per resolution element using a 1024×2048 section of a Hawaii-II HgCdTe array. The entrance slit is 1×30 arcseconds (at Palomar) and the spectrum is spread over five orders in the cross-dispersed design. A notable feature of TripleSpec is that it has no moving parts. Information on the design details of TripleSpec can be found in Wilson et al. (2004)[4]. Here we give just a few specifics. Briefly, light from the telescope passes through an Infrasil (quartz) window where two off-axis paraboloids reimage the telescope focal plane onto the slit while converting from f/16 to f/10.6. The slit plane consists of an aluminized silicon wafer tilted at 30 degrees to the beam. The (projected) slit width is 261 μm. Reflected light is sent to an internal 1024x1024 slit viewer camera which gives a 4.3×4.3 arcminute field-of-view. The light passing through the slit proceeds to the spectrograph (see Figure 1). This optical path consists of a reflective off-axis, parabolic collimator, two fold mirrors, a cross-disperser stage with three prisms (2 ZnSe and 1 Infrarsil), and a grating before entering a 7-element camera assembly which focuses the dispersed light onto the detector. The mirrors are gold-coated and all other optics (except the grating) are anti-reflection coated. Our original goal was to extend the wavelength

Ground-based and Airborne Instrumentation for Astronomy II, edited by Ian S. McLean, Mark M. Casali,
Proc. of SPIE Vol. 7014, 70140X, (2008) · 0277-786X/08/$18 · doi: 10.1117/12.789660

coverage to 0.85 μm but the anti-reflection coatings could not be simultaneously optimized for J, H, and K bands while maintaining good performance below 1 μm. A paper which gives design and performance details on the completed spectrograph is in preparation[5].

TripleSpec was commissioned at Palomar during the fall 2007 and spring 2008 observing semesters at Palomar. Here we present some of the results from instrument commissioning.

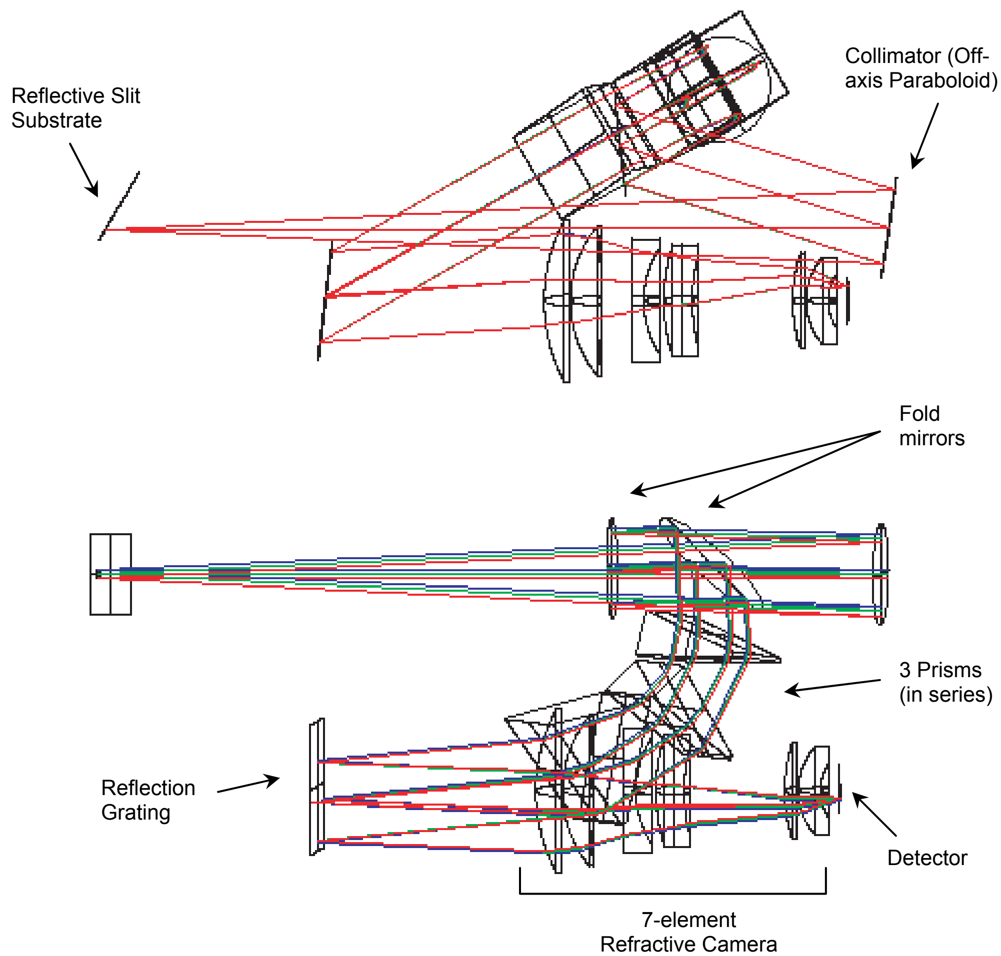

Figure 1: Schematics of the spectrograph portion of TripleSpec. The bottom schematic is rotated by 90 degrees relative to the top view. Light that passes through the slit is collimated by an off-axis paraboloid and then folded by two flats for packaging purposes. The beam is then pre-dispersed by three prisms in series before reflecting off the grating. Lastly, the dispersed light in re-focused onto two quadrants of a HAWAII-II HgCdTe detector by a 7-element refractive camera.

2. SYSTEM THROUGHPUT/RESPONSE

A major design goal was to achieve high throughput, a somewhat difficult task given the wide wavelength coverage. TripleSpec has 11 transmissive elements, 5 gold coated mirrors, and a grating. Figure 2 shows the transmission for individual optical elements. Where tested there was good agreement between the design specifications and witness samples. Figure 3 displays the combined transmission of all optical elements and Figure 4 shows the predicted performance vs. that measured at the telescope.

In general the throughput is excellent, in the 20-30% range for the H and K bands. However, J-band is about a factor of two lower than expected. We had some suspicions that this is due to the ZeSe prisms. To check this, an FTS transmission measurement was performed on the prisms. Two prisms were scanned together to give an undeviated beam but the large thickness of the combination (and thus presenting difficulties with using the FTS) makes the results suspect. The FTS-measured transmission is significantly lower than the predicted throughput of the prisms. The revised prediction based on these measurements is the one shown in Figure 4. Even so, this still over predicts the observed throughput. As of this writing, this issue is unresolved.

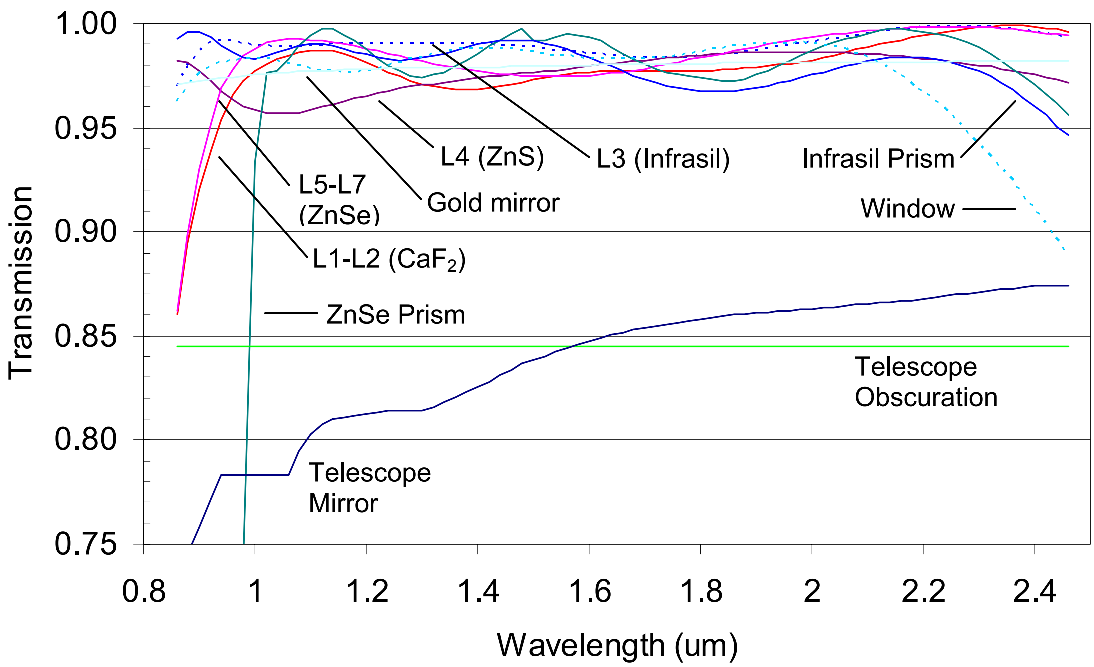

Figure 2: Transmission of various optical elements in TripleSpec. These are for a single element, e.g. the L1-L2 curve must be squared and the gold mirror transmission is raised to the fifth power to account for the five mirrors in the system. L1 through L7 are lenses in the spectrograph camera. The detector responsive quantum efficiency is taken to be 0.70 and falls off the bottom of the plot. The telescope obscuration and past measurements of telescope mirror reflectivity are included in the plot as well.

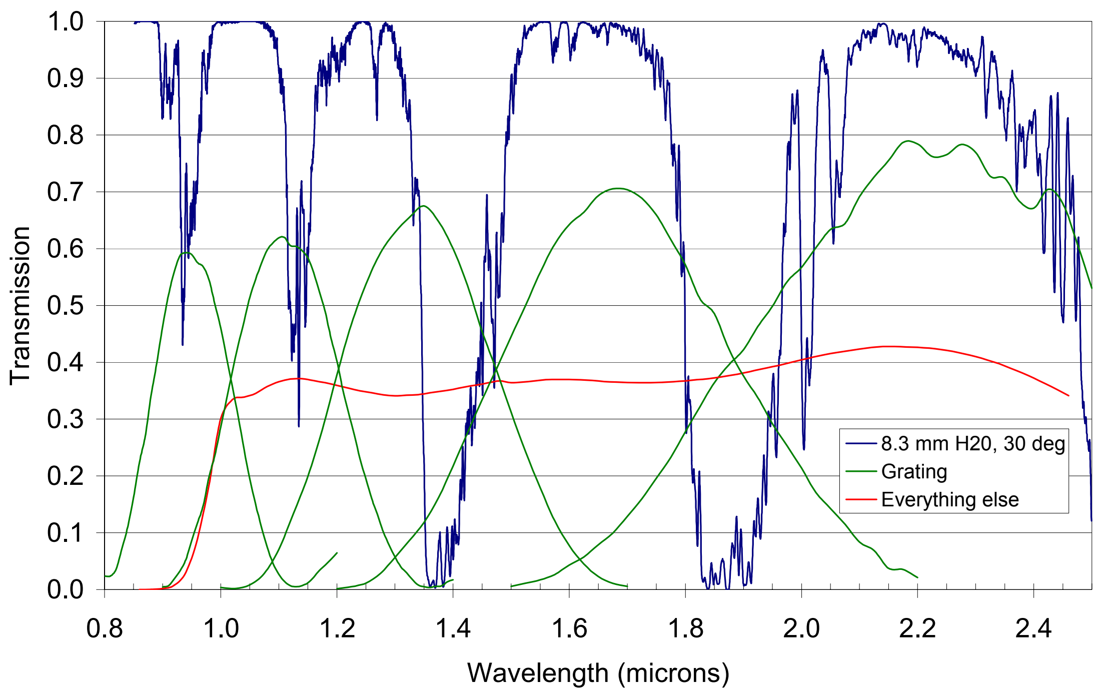

Figure 3: Throughput breakdown for TripleSpec. The "Everything else" curve includes all optical elements from Figure 2 and the detector. The measured grating performance is shown and an ATRAN computation of a humid atmosphere for an elevation of 5000 feet is given as well.

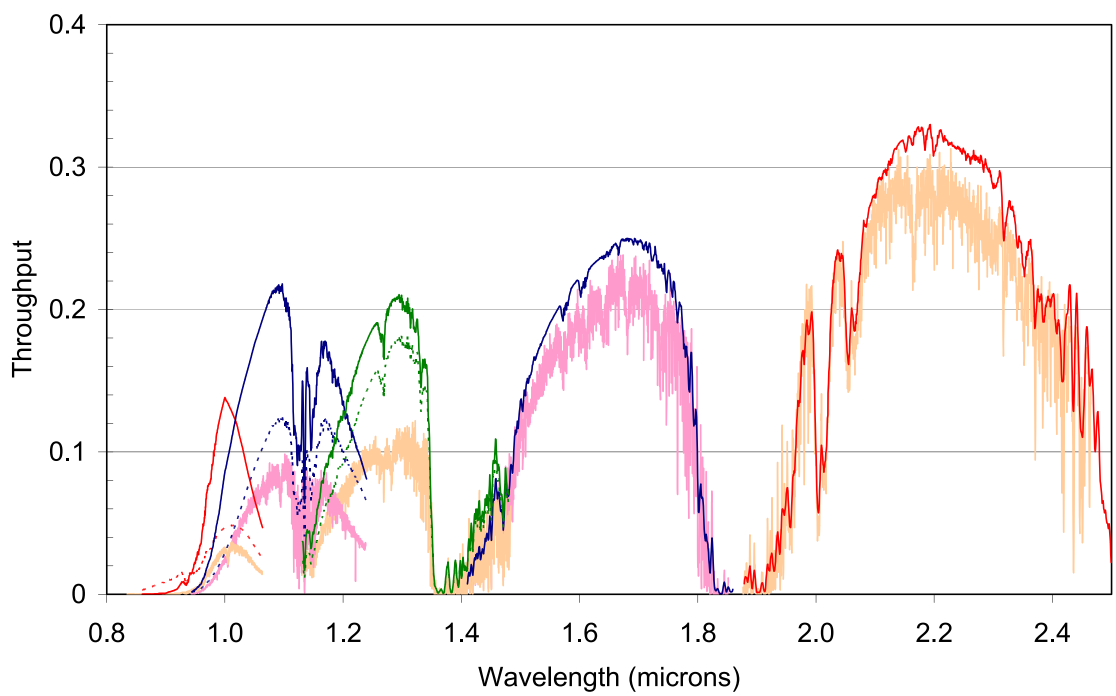

Figure 4: Comparison of predicted vs. measured (fuzzy, lower spectrum) throughput (top of the atmosphere to detected photons) for TripleSpec. A slit loss of a factor of 2 has been assumed (and taken out). For 0.9 – 1.4 μm, the upper curves use the vendor estimated ZnSe prism performance while the middle (dashed)

curves use an FTS measurement done by us (see discussion above). The instrument throughput (removing atmosphere, telescope, and detector contributions) is about a factor of two greater at all wavelengths.

3. SKY EMISSION

Figures 5 displays a TripleSpec image of the near-infrared background on the Palomar 5-meter telescope. This background is a combination of sky and telescope emission. The order layout is easily seen in this view. The top three orders cover K, H, and J band respectively. Figure 6 shows extracted background signal.

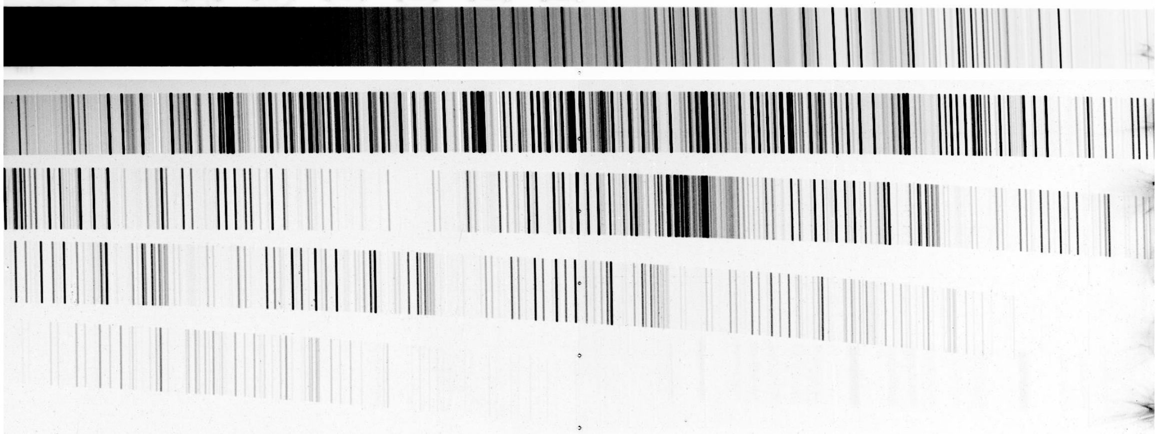

Figure 5: TripleSpec background showing thermal background emission (upper left) and OH sky emission lines. From top to bottom the orders are 3 (2.46 – 1.88μm), 4 (1.85 – 1.41μm), 5 (1.49 – 1.13μm), 6 (1.24 – 0.94μm) and 7 (1.06 – 0.93μm). Order 3 has been scale separately from the rest of the spectrum. The spectrum is 600 second exposure taken near zenith (air mass = 1.08) on February 16, 2008.

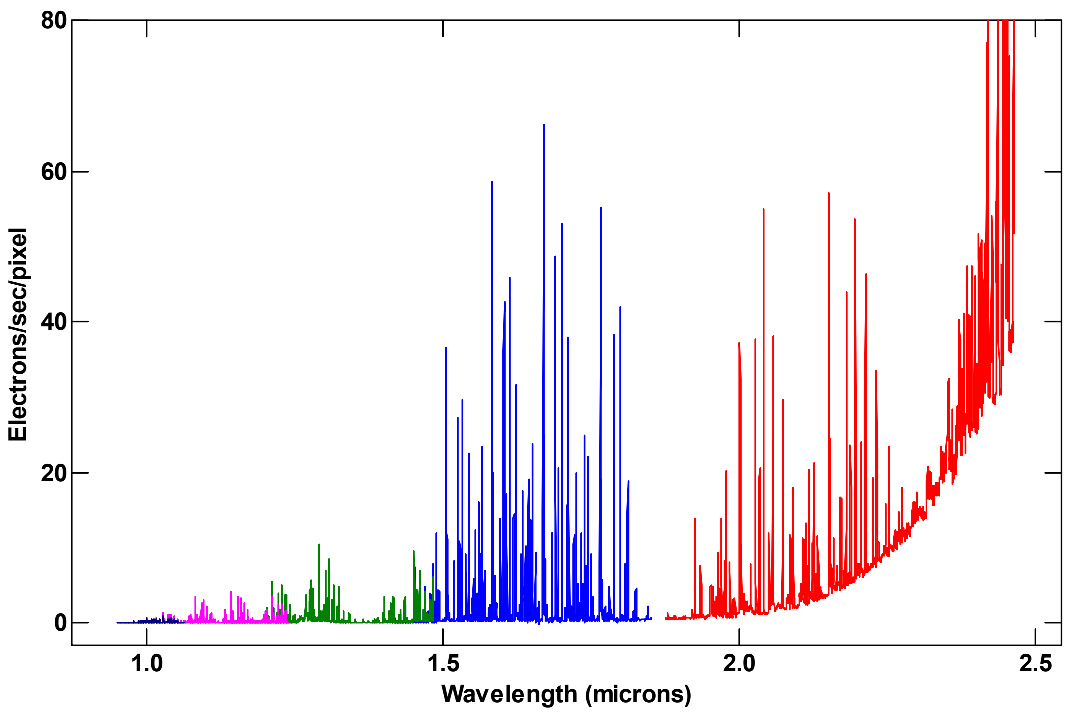

Figure 6: Plot of sky plus telescope emission for TripleSpec in units of photo-electrons/sec/pixel extracted from Figure 5. Note that the pixel size is 0.37 arcseconds and the system throughput is approximately 10, 20, and 30 % near the center of the J, H and K bands respectively. The clipped emission features on the right-hand-side of the spectrum reach approximately 100 e-/sec/pixel.

Always of interest is the inter-OH emission, particularly in the J and H bands. This is quite difficult to measure since there is some cross-talk in the array which causes an offset of ~ 0.6% of the average signal along the readout direction both within a quadrant and across quadrants. This is removed but introduces an uncertainty in the zero level. Dark current in the array (~ 0.085 e-/sec) is subtracted off via extrapolation from un-illuminated portions of the array. Finally there may be scattered light from the OH-lines. No correction is applied for this. Thus we consider our calculation a rough upper limit to the inter-OH sky. The background, I_ν, (in e.g. mJy/sqr-arcsec or MJy/sr) is related to the signal detected, S (in e-/sec/pix), as:

$$S(\lambda) = \frac{I_\nu \Delta\nu}{h\nu} A_T \tau_{inst}(\lambda)\, \theta_{pix}^2 \Rightarrow I_\nu = \frac{hR}{A_T \theta_{pix}^2} \frac{S(\lambda)}{\tau_{inst}(\lambda)} = 76 \frac{S(\lambda)}{\tau_{inst}(\lambda)} \quad (\mu\mathrm{Jy}/''^2)$$

where the spectral resolution (R = 2700), telescope area (A_T = 17.13 m^2), and pixel size (θ_{pix}= 0.37 arcsec) have been inserted to give I_ν in units of μJy/arcsec^2. Accounting for the factors above, the inter-OH continuum over the J and H-bands ranges from 0.05 – 0.8 photon/sec/pixel corresponding to 4 to 60 μJy/arcsec^2 and consistent with other measurements[6, 7].

4. SYSTEM RESPONSE

Figure 7 shows the response to a 10th magnitude A0V star. The result was obtained by a measurement of the H = 5.66 star, HD 29526 and scaling appropriately. No correction has been applied for slit losses so under better or worse seeing conditions, this result will change. In addition, during this period the image quality was compromised due to issues with the 5-m mirror mount.

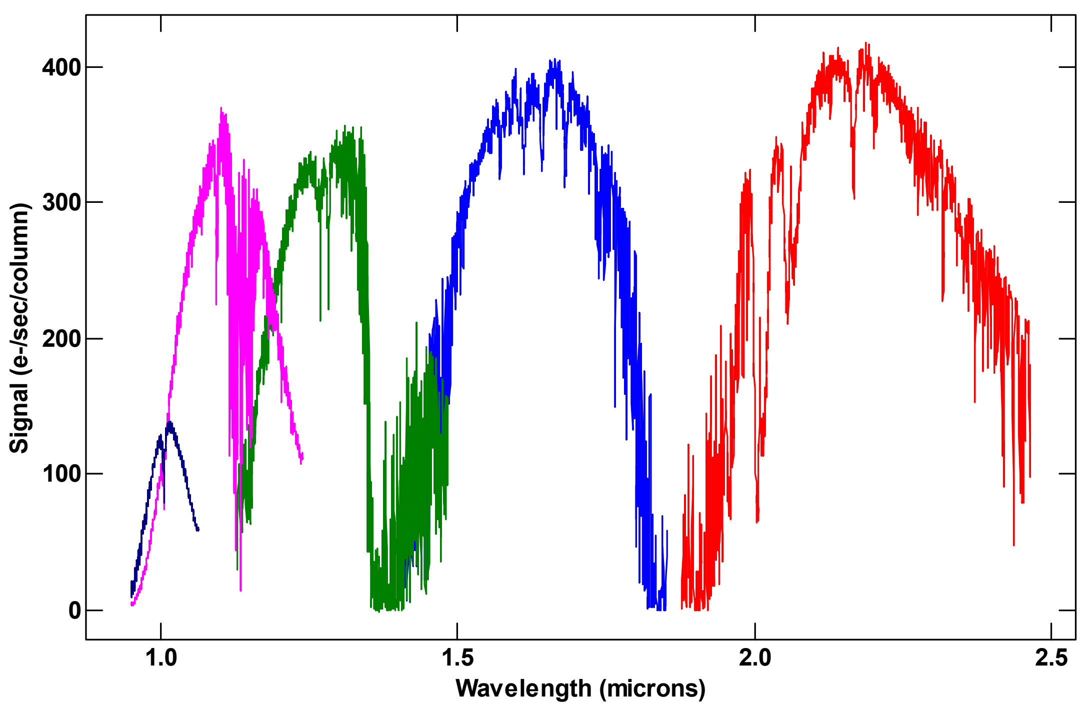

Figure 7: TripleSpec response to a 10th mag A0V star. The vertical axis is the integrated signal in electrons/sec along a column. No correction has been applied for slit losses, so this result is seeing dependent.

5. SENSITIVITY

Using the measured read noise, dark current, sky and telescope background, and system response, we can estimate the sensitivity of TripleSpec for different observing scenarios. Figure 8 and 9 show estimates of the signal-to-noise per column for an A0V-type object with H = 15 and 17 in total integration times (combining exposures) of are 120 and 1500 seconds respectively. For these calculations a factor of two throughput drop due to slit loss is assumed (this gives consistency with Figure 4). The sensitivity can be improved by coadding across the three pixels per resolution element without much loss in information for continuum sources.

As expected there is a marked decrease in performance in the presence of OH lines. The upper envelope highlights the inter-OH regions which result in the best sensitivity. Because of the presence of the OH lines and continuum background, it is necessary to do a "sky" subtraction. If not done properly, this subtraction can cause the usual square-root of two loss in sensitivity. One technique is to interpolate along the slit to remove the background. Another technique is to measure the source at a number of positions along the slit (e.g. 5), median filter (or use some other clipping algorithm) and subtract the result to remove the background but not the source. In practice, the OH lines vary enough for integration times longer than 60 seconds that a hybrid technique appears to work best: subtract along the slit then do a subtraction of a median image for a final "clean-up." The resulting instrumental performance is very near our expectations.

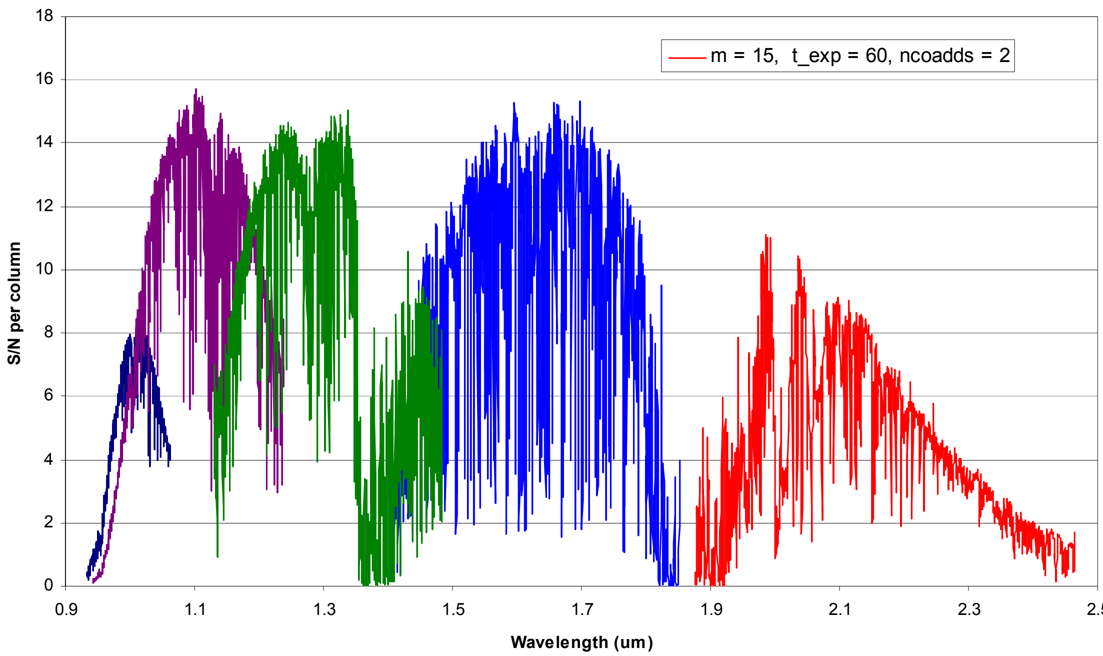

Figure 8: S/N ratio per column for an m = 15 (A0V type) source for two 60 second exposure combined together. Coadding across a resolution element (3 pixels) will decrease the number of coadds by a factor of 3 or (for fixed number of coadds increase the S/N by a factor of sqrt(3). No differencing noise is included.

6. CONCLUSIONS

TripleSpec is a state-of-the-art near-infrared spectrograph that simultaneously covers the spectral range from 1-2.5 microns at a spectral resolution of 2700. Commissioning on the 5-m Palomar telescope shows the instrument works very near its predicted performance. Another "copy" by the University of Virginia is now in operation at one at Apache Point Observatory and a third copy will be deployed by Caltech for use at Keck Observatory within the next six to twelve months. TripleSpec is also being used with an externally dispersed interferometer to search for exoplanets[8].

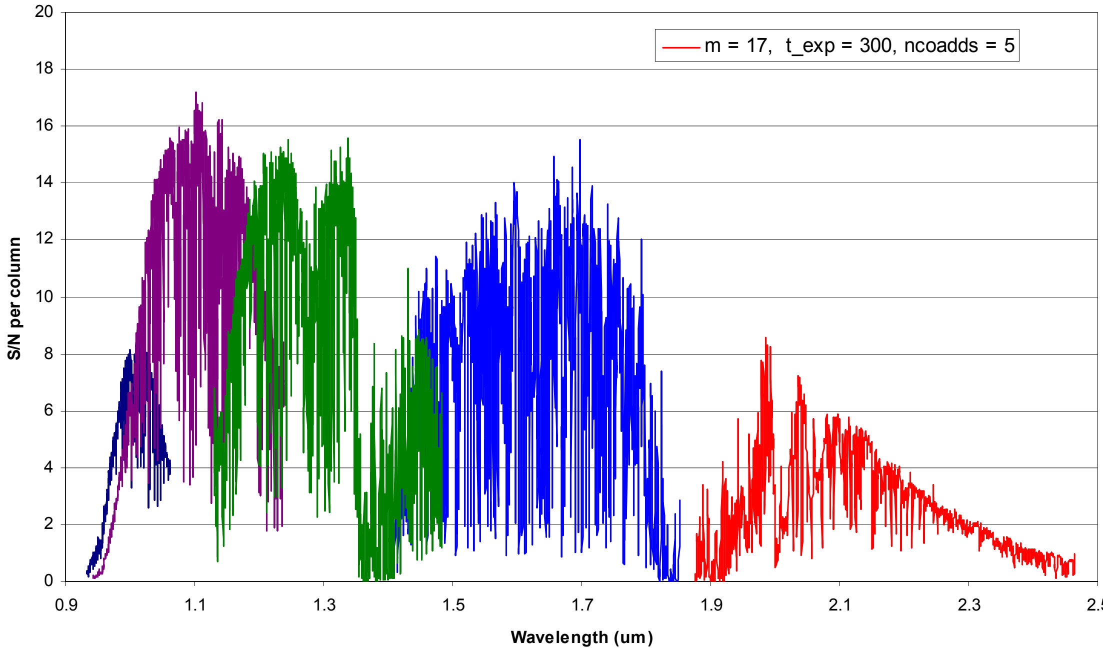

Figure 9: S/N ratio per column for an m = 17 (A0V type) source for five 300 second exposure combined together (total integration time of 1500 seconds).

7. ACKNOWLEDGEMENTS

We gratefully acknowledge the help and support of Mike Ressler and Nick Gautier at the Jet Propulsion Laboratory at Caltech in the purchase of a number of hardware items for TripleSpec including the spectrograph detector, the cryostat, and spectrograph camera. We also thank the Palomar staff for their excellent support during TripleSpec commissioning.

8. REFERENCES

1. Skrutskie, M.F. et al., "The Two Micron All Sky Survey (2MASS): Overview and Status," in The Impact of Large Scale Near-IR Sky Surveys, F. Garzon et al., eds., Kluwer Academic, Dordrecht, 25, (1997).
2. York, D.G et al., "The Sloan Digital Sky Survey: Technical Summary," AJ, **120**, 1579, (2000).
3. Werner, M.W. et al., "The Spitzer Space Telescope Mission," ApJS, **154**, 1 (2004).
4. Wilson, J. C. et al., "Mass producing an efficient NIR spectrograph," in Ground-based Instrumentation for Astronomy. Edited by Alan F. M. Moorwood and Iye Masanori. Proceedings of the SPIE, **5492**, 1295-1305 (2004).
5. T. Herter et al., "TripleSpec: An R =2700, 1-2.45 μm Spectrograph," in preparation.
6. Maihara, T., et al, "Observations of the OH airglow emission," PASP, **105**, 940 (1993).
7. Gillett, F. C. and Mountain, M., "On the Comparative Performance of an 8 M NGST and a Ground Based 8 M Optical/IR Telescope," edited by Eric P. Smith and Anuradha Koratkar, ASP Conference Series, **133**, 42 (1998).
8. Edelstein, J. et al., "Dispersed interferometry for infrared exoplanet velocimetry," in Ground-based and Airborne Instrumentation for Astronomy II. Edited by Ian S. McLean and Mark M. Cassali, Proceedings of the SPIE, **7014**, this conference (2008).